Agricultural Anaerobic Digestion Fundamentals for Understanding, Evaluating and Applying

Colorado Governor's Office of Energy Management and Conservation

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Colorado Department of Public Health and Environment

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

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For more information, contact:

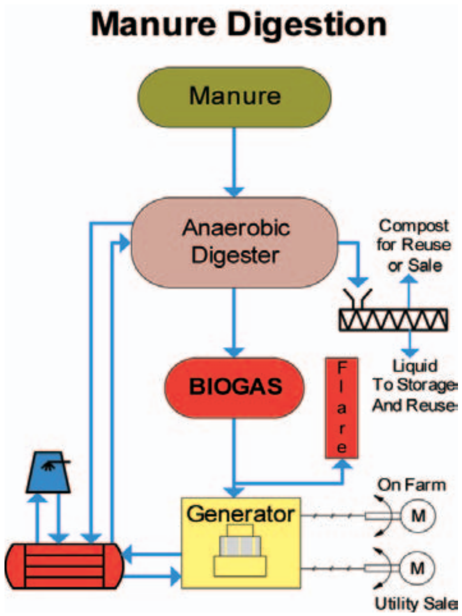
Colorado Governor's Office of Energy Management and Conservation
225 East 16th Avenue, Suite 650
Denver, CO 80203
303-894-2383
www.state.co.us/oemc

Colorado Department of Public Health and Environment
4300 Cherry Creek Drive South
Denver, CO 80246
303-692-2000
www.cdphe.state.co.us

Environmental Systems and Solutions, LLC.
John D. Ewing, P.E.
7339 Shoreham Place
Castle Rock, CO 80108
303-660-0757

Overview

An anaerobic digester (AD) in simple terms contains a natural biological (bacterial) process that primarily converts organic carbon from large molecules (carbohydrates, sugars, fats and proteins) to simple molecules (carbon dioxide, methane, water and biomass). The conversion is part of natures carbon (re)cycle that when properly applied can effectively assist in sustainable, economical, environmentally balanced and neighbor friendly agricultural practices. The primary advantages are energy recovery, reduced greenhouse gas emissions, odor mitigation, and nutrient management. The net economics of applying AD varies dramatically based on geography, facility size, electrical rates and usage and frequently on utility cooperation with buy-back programs. Furthermore, much attention is growing on the concept of co-digestion (Community Digesters) where non-farm organic sources are blended with those from the farm, to produce greater quantities of methane for increased energy recovery. The basic principles and most of the major factors affecting an agricultural AD decision are addressed herein.



Anaerobic Metabolism

Anaerobic bacterial metabolism leading to methane production is a multistep process that is illustrated below. Two distinctly different types of bacteria are required with the first group being bacteria associated with a wide variety of common fermentation actions. The fermentation bacteria are generally the same as those commonly associated with many cultured dairy products and on-farm activities such as silage and composting. Methanogenic bacteria (methane producing) require the presence of the organic acids produced by the fermenters. Ironically, acid substrates are required for methane formation while a near neutral pH is required for most efficient production. Like all biological processes, temperature impacts the rate of both metabolic steps. The vast majority of AD systems operate at or near 95-105 degrees F (mesophillic). Some systems utilize temperature ranges at or above 125 degrees F (Thermophilic). Experience has shown that mesophillic digesters are most desirable due their overall stability and ease of operation. The common benefits stated for thermophilic digesters relate to marginally more gas production, quicker pathogen kill and greater volatile solids reduction. There are some claims relative to fewer odors in the final product as well. It is important to note that all systems can be inhibited by indiscriminant use of persistent antimicrobial agents.

Common Approaches - On Farm Manure Handling and Digestion

The most common methods for storing or processing manure are listed below, described in the next column and graphically shown on the next page. They are:

- Open Lagoon
- Membrane Covered Lagoon
- Heated and Mixed Membrane Covered Lagoon
- Plug Flow Digester
- Complete Mix and Hybrid Digesters
- Fixed Film Digester
- Upright Cylinder Digester

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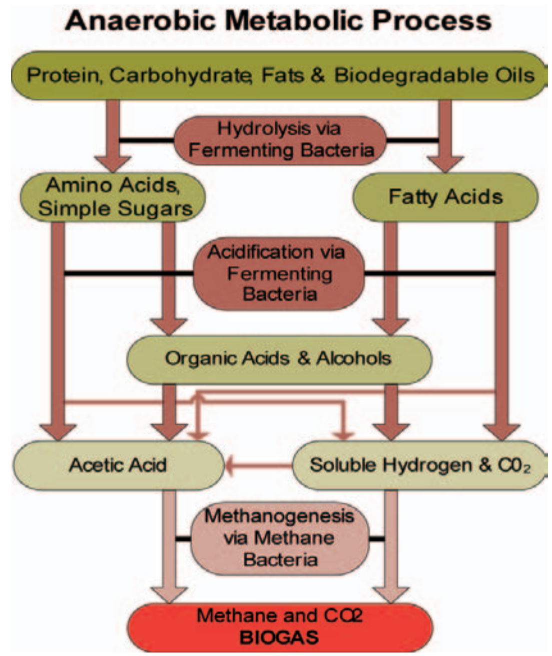

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General Application Issues

Manure Nature and Handling – Efficient and appropriate manure handling at the front and back is crucial to the overall success of any on-farm digestion system. Inappropriate handling can hinder, severely restrict or even wipe out the operation. It is absolutely imperative that a well defined manure management system be developed and understood relative to its down stream impacts on the management and disposal system. The considerations that must be evaluated include:

- Bedding (Straw, wood chips, sand, compost)
- Bedding Material Recovery
- Scrape and flush
- Flush
- Vacuum collection

Each containment, digestion and management approach can be severely impacted if the manure is not properly conditioned prior to entering the system. In general the least impact is caused by compost bedding and the greatest negative impact is caused by sand bedding. A complete analysis of the overall costs involved in managing each material is imperative to financial and operational success.

Open Lagoon – Open lagoons and pits have been the prevalent approach for holding and managing manure since farms began processing and containing the animals in large enough quantities that substantial manure volumes required containment. Open lagoons and pits are rapidly being eliminated due to odor and insect nuisance issues. Lined open lagoons are still used where neighbors or urban development are not an issue. These require large land areas but if land is low cost, are the lowest initial cost systems and require little or no operation other than final disposal.

Open Lagoon

Membrane Covered Lagoon – Membrane covered lagoons are rapidly appearing as the low cost method of choice to mitigate odors and insect issues. Most are designed to contain the off gases so that they can either be burned in a flare to eliminate odors or often, the gas is fully utilized for energy and heat recovery. Similar to open lagoons, these require large land areas but again, if land is low cost, they are generally the next lowest cost systems and require little or no operation attention other than final disposal. Several liner/cover system vendors are available with high quality and reliable equipment.

Membrane Covered Lagoon

Heated and Mixed Covered Lagoon – This modification is the next step for a lagoon and can be quite cost effective. The capital and operations cost of the insulated cover is substantially higher than a simple cover but the lagoon size drops substantially and energy recovery can be very good. Limited vendors have successful systems available.

Plug Flow Digestion – The plug flow (PF) digester is the next step down in size requirement and generally represents a substantial increase in capital and operations effort. A PF digester functions like its name in that the manure is kept viscous enough to pass as a "plug" through the vessel. PF digesters are typically sized for a 20 day holding time and can achieve reasonable volatile solids reduction and biogas production. Numerous designs have been developed and many have either failed or have been abandoned due to operational issues or net economics. Several successful systems are in operation and are currently being designed and built as well.

The most common systems typically have biogas supported membrane covers that resemble air structures used for sport facility enclosures. Fixed covers have been used but have experienced many more operational challenges than floating covers. A PF digester *must* be heated in order to accomplish methane production. The most common heating system consists of internal hot water piping placed along the bottom outside edges. These pipes are most commonly schedule 40 uncoated carbon steel. A properly operating digester is a non corrosive environment and these pipes have been found to last many years. PF digesters must be cleaned periodically due to the buildup of materials that restrict volume and efficiency. Typical times between cleanings average about 10 years. It is common to find as much as 40% of the digester rendered ineffective in this time. The symptoms of plugging are reduced volatile solids reduction and biogas production. Particular care relative to operations and reference checking should be exercised prior to system selection.

Complete Mix Digester - Complete mix digesters are typically designed with similar material holding times to plug flow digesters and generally consist of a covered bolted steel vessel with external pumps and heating equipment. The term complete mix implies that the contents are continuously mixed and heated. This may or may not be true as it has often been found that the continuous mechanical operation leads to significantly increased maintenance and operations costs. These are often operated intermittently with reasonable success. Complete mix digesters

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Heated & Mixed Membrane Covered Lagoon

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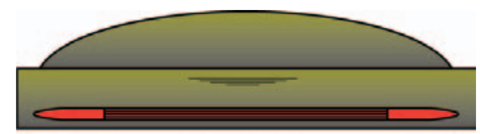
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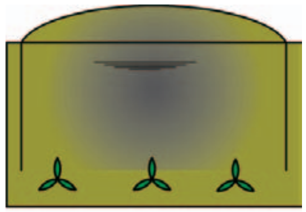
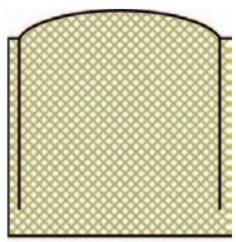


Complete Mix or SBR

Fixed Film Digester - This type of digester uses a vessel similar to the complete mix system but contains plastic media over which the manure is spread and allowed to trickle down to the bottom. Here it is either recirculated back to the top or discharged to a holding system. Fixed film designs require very dilute well screened material to prevent plugging and are generally only considered when flushed manure management is used. With proper screening and separation nearly any bedding material can precede a fixed film system.



Fixed Film

There is limited experience with this approach but much research has indicated that a sound design is possible. Capital costs are generally higher than plug flow and similar to complete mix but excellent volatile reduction and gas production have been achieved.

Upright Cylinder Digester - Upright cylinder digesters (UCD) use a small diameter, tall design much like the classic silage storage silo commonly seen on farms. This design has been shown to achieve very good volatile solids reductions at about 1/4th the detention time of plug flow or complete mix systems. The reason for this focuses on the physical and hydraulic contact achieved with a long column of material through which all new material must pass. Also, solids accumulation and proactive mixing at the top and bottom of the UCD allow much more intimate contact with high solids (high bacterial concentration) than plug flow or complete mix systems. Furthermore, the UCD can be designed in a much more modular approach than other designs requiring large vessels and long holding times. The combination of modularity, small footprint, shorter holding times and mechanical simplicity all may lead to improved initial and long term economic advantages for the UCD design as more are implemented. This design is compatible with all but high volume flush systems common to sand bedding operations. When applied properly, the UCD design has been shown to provide a number of capital and operations advantages to classic designs. This design is also very compatible with co-digestion of offsite organics due to the continuous feeding and recirculation allowing efficient blending and microbial exposure.

Biogas Production, Handling and Utilization

Though there are numerous operational benefits to managing and containing farm manure such as odor, storm water and insect control, by far the biggest source of interest with manure containment and anaerobic digestion is the production of biogas and its utilization. It turns out there are nearly as many ways or combinations of technologies to use the available energy in biogas as there are ways to produce it. Common to all systems is that biogas is contained and combusted. The resulting flame is either flared or preferably utilized to produce valuable quantities of electricity and/or heat for on-farm energy reduction and in many cases, off-farm energy sales.

What is Biogas?

Methanogenic metabolism produces essentially equal quantities of methane (CH_4) and carbon dioxide (CO_2). However, biogas in nearly all manure digesters will typically be 65% CH_4 and 35% CO_2. This variance is due solely to the high solubility of CO_2 and low solubility of CH_4. This solubility difference means that a substantial portion of the CO_2 dissolves in the liquid while the methane is released. A point to note is that this characteristic also explains why landfill biogas has a lower BTU content and is nearly always close to the 50-50 ratio as there is no water for the CO_2 to dissolve into. Biogas energy value or BTU content is directly proportional to the % CH_4. Pure CH_4 has a BTU level of approximately 1000 BTU's per cubic foot so the BTU content of biogas is linearly reduced by the percentage, leaving a common content of about 650 BTU's per cubic foot. Any variations claimed by a system provider will be strictly associated with the dilution. In this regard, flushed manure systems will generally produce higher BTU gas due to the CO_2 being dissolved in the higher volume of water. Though the biogas is higher in BTU's flush systems must consume more onsite energy to heat all that water for digestion and thus there is generally a negative net energy benefit.

Hydrogen sulfide (H_2S) is the other trace gas commonly present in manure biogases and is the one responsible for nearly all the negative press. It may range from 0.2% to over 1%. Bovine manure will generally be just above 0.2% while porcine manure have often been chosen for their smaller footprint, cleaner overall design, easier management and somewhat improved gas production from plug flow and lagoons. Generally, both capital and operations costs are higher than plug flow or lagoons. Like plug flow systems, there are several variations/modifications to the complete mix approach. The variations (hybrids) typically incorporate techniques or technological approaches that are very similar to classic wastewater treatment processes. These generally involve some form of solids concentration step that is either mechanical (DAF) or gravity based (clarifier). Prior to selection, check for sound design and preferably operations experience with the type of bedding system being planned or used. When operated in the sequencing batch reactor (SBR) mode, batch feeding is utilized and mixing is intermittent. Biogas production is highly variable with SBR designs which lead to unique energy recovery challenges.

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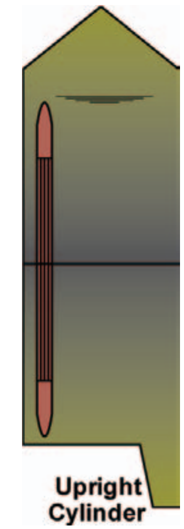

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Unfortunately, sulfur emissions can become an issue in large systems and must be carefully considered in any biogas utilization plan. The issues will range from system design to equipment selection and air quality permitting. The most common solution when sulfur emissions must be reduced is an iron sponge scrubber. The iron in the sponge (wood particles) reacts with the sulfur to yield iron sulfide. The sponge may be regenerated and/or disposed as a soil amendment. Some care is required depending on the scrubber design and operation.

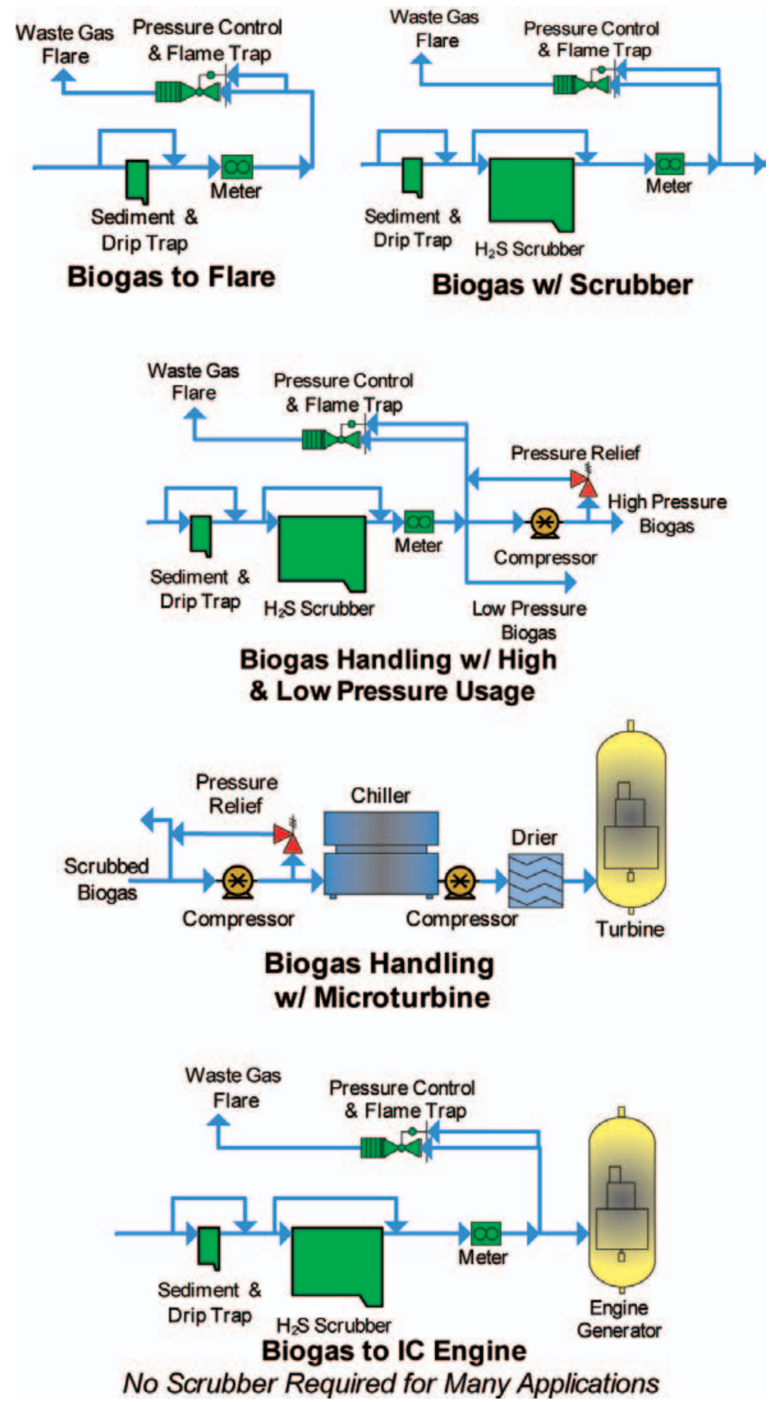
Biogas Utilization

All that energy available in biogas has led to numerous system designs. Every system has common features as well as unique components to address the specific installation characteristics and geography. The following figures graphically illustrate some of the common systems. In general, biogas utilization is accomplished with one or more of the following steps whose order in the process will depend on the system:

1. Collection piping
2. Moisture and sediment control
3. Pressure management and control
4. Hydrogen Sulfide management and control
5. Utilization rate and/or storage
6. Combustion and energy utilization

Several common flow schematics follow that illustrate a wide variety of ways that digester biogas may be handled. Similar to digesters however, there will be specific design requirements for each system that will dictate the final layout.

Biogas w/ Scrubber



Waste Gas Flare
Pressure Control & Flame Trap
Meter
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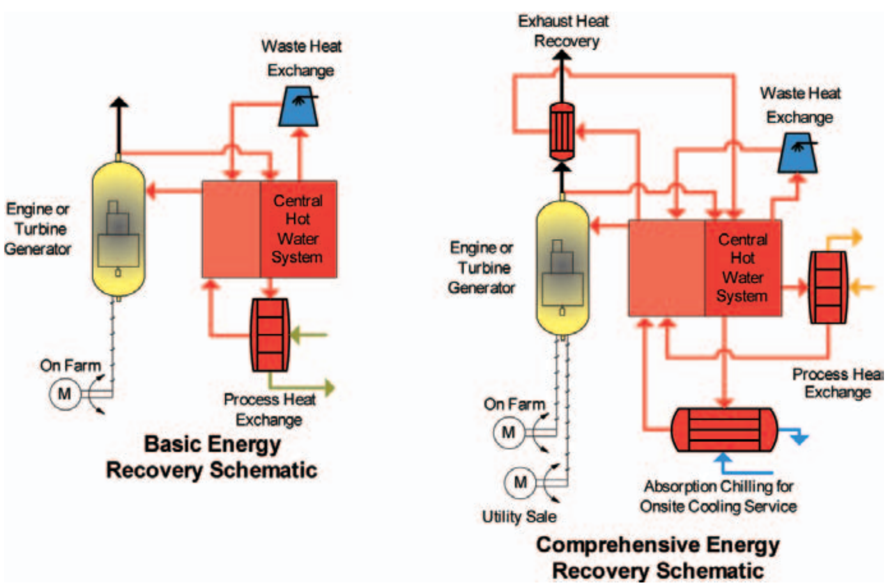
Chiller
Drier
Scrubbed Biogas
Compressor
Compressor
Turbine
Biogas Handling w/ Microturbine
Waste Gas Flare
Pressure Control & Flame Trap
Meter
Sediment & Drip Trap
H_2S Scrubber
Engine Generator
Biogas to IC Engine
No Scrubber Required for Many Applications

Energy Recovery

When biogas is not simply flared where odor control is the primary goal and is utilized for energy recovery, there are several options available depending on the digester, the overall operation, utility costs and need for heating and/or cooling in both the digester and adjacent facilities. In cases where a digestion facility is required just for environmental compliance for odor and/or water pollution regulations, the next step to energy recovery can often be very cost effective. Regardless of the circumstances, some of the factors that must be considered when energy recovery is involved are:

1. Energy equipment capital and operations costs.
2. Local electrical energy costs.
3. Onsite electrical and heat usage that will be offset.
4. Cooling requirements for adsorption chilling options.
5. Air emissions restrictions for combusting biogas.
6. Utility energy buy-back program opportunities or obstacles.

The following schematics illustrate common energy recovery systems.



The Community Digester Concept

As knowledge and experience with agricultural manure digesters have grown, it has become readily apparent that many designs are capable of accommodating fairly substantial quantities of outside biodegradable organic materials. The two general benefits to this practice are typically increased biogas production which translates to greater energy recovery and tipping or hauling fees which can often be collected from the entity generating the organic material. Almost without exception, the organics are coming from a food production facility. The following industries commonly have the need to dispose of high strength organics either onsite or via offsite disposal or land application systems:

1. All aspects of dairy processing, including ice cream, cheese, yogurt, sour cream, milk condensing and bottling.
2. Brewing and beverages of all types, (beer, distilled spirits, wine, juice, soda).
3. Neutraceutical Production (Nutrient Drinks such as Slim Fast, Ensure).
4. Fruit and Vegetable processing.
5. Prepared foods production, frozen meals to salad dressing.

The following schematic illustrates where outside organics can fit into the process.

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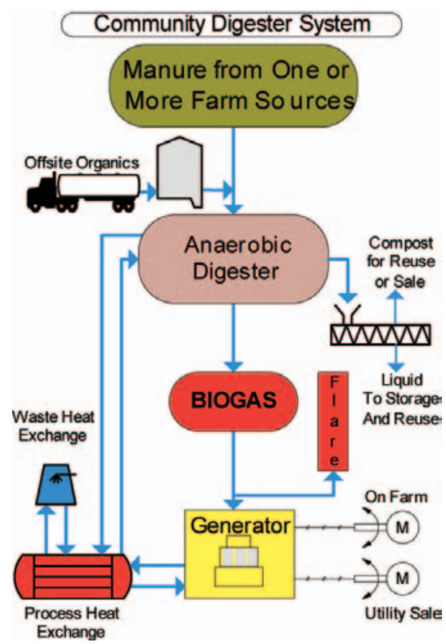


The community digestion concept is a fairly recent development and, like many other practices, must be approached with solid knowledge and understanding of what the impacts may be on the basic digester. The key technical reason why off-farm organics can be successfully placed in a manure digester is that by its very nature, manure consists of a culture of starving microbes. The material we call manure has passed through a very efficient digester, the ruminant gut, before it hits the ground which means that the microbial population has done its intended job by providing the host animal with sustaining energy, vitamins and an array of nutrients that were all derived from the raw food. At the end of the trail, there is relatively little soluble material available compared to the trail head.

The technical advantage is that there is a constant supply of healthy anaerobes and methane formers in the manure and if placed in the optimum condition for performing what they thought was a finished task then voila, we have an opportunity to use them as starter culture for another job. Placing readily digestible organics in a manure digester is the equivalent of bypassing the first digestion phase and placing a soluble source of sugar or fat directly into the hind gut of a production animal. Any farmer with animal experience can imagine the (negative) impact that practice would have on the animal. When proactively and knowledgably placed in a manure digester the practice can result in a substantially positive result. The practice has been successful in nearly all digester designs but is best applied to those with active mixing and/or recirculation where dosage controls can be managed. Methane is produced at a rate of approximately 5.6 ft^3/lb. of COD reduced. When considering co-digestion on any material, the following procedure can be used for evaluating methane production potential. The example shown is for a material such as whey from a dairy operation:

- **Calculate the lbs of COD available:** (Waste Vol. (gal)/1,000,000) x COD (mg/L) x 8.34 = lbs. COD

50,000 gal/1,000,000 x 100,000 mg/L x 8.34 = 41,700 lbs. COD

- **Calculate the methane production potential:** Lbs. COD x 5.6 ft^3/lb. COD = ft^3 Methane

41,700 lbs. COD x 5.6 ft^3/lb. COD = 233,520 ft^3 Methane

The subsequent methane value is then dependent on the overall system economics. The best value is achieved in co-digestion when a fee can be charged for accepting the waste and the energy can be fully utilized for heat and/or electricity values. The approximate value of the methane produced for this example using a historical value of natural gas at $0.40/therm is approximately $934. The annual value then is a function of annual production. If available every day and the system design is capable of accommodating the material, the annual value of the methane would be

approximately $341,000. There are many factors that will affect the feasibility and overall net value but if a tipping fee can be charged as well as realizing the methane value, co-digestion can add attractive value to an agricultural digester.

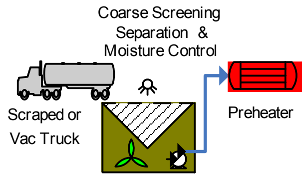
There are nearly always a very wide range of compatible co-digestion materials available in most communities. Some considerations to keep in mind are listed below:

- Low pH organic acid materials and saturated animal fats, oils and grease have very high methane potential and when properly blended have very high reaction rates.

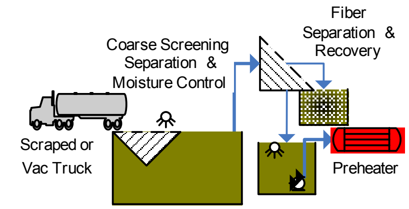
- Simple carbohydrates and sugars can easily overload a digester by dropping the pH below methane former optimum production. Cellulosic materials will be the least productive.

Manure Handling

Even with the best digestion system possible, inefficient and/or ineffective manure handling on the front or back end of the project can dramatically impact the system economics. Material handling, planning and design must be integral to the overall system or the chance of poor to non-sustainable operations is greatly increased. The figures and discussions below illustrate a range of systems and issues that merit in-depth consideration.

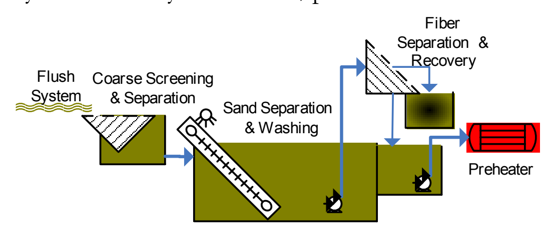


Raw Manure Handling w/ Fiber Bedding



Raw Manure Handling w/ Fiber Bedding

When using a fiber bedding program, the operator must decide whether to separate the fiber before or after the digester. Fiber separation can be accomplished with side hill screens when the manure is dilute or screw presses when it is more concentrated. The digestion system's ability to handle/pass fibrous materials will dictate the selection.



Raw Manure Handling w/ Sand Bedding

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- **Calculate the lbs of COD available:** (Waste Vol. (gal)/1,000,000) x COD (mg/L) x 8.34 = lbs. COD

    50,000 gal/1

- **Calculate the methane production potential:** Lbs. COD x 5.6 ft³/lb. COD = ft³ Methane

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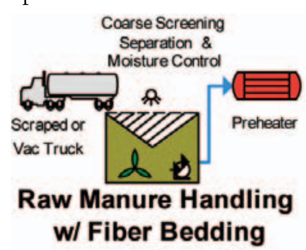

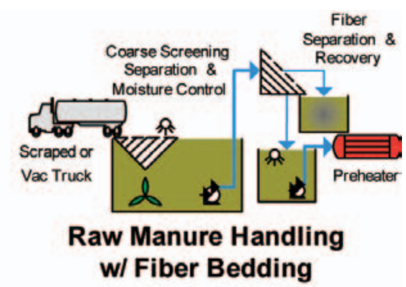

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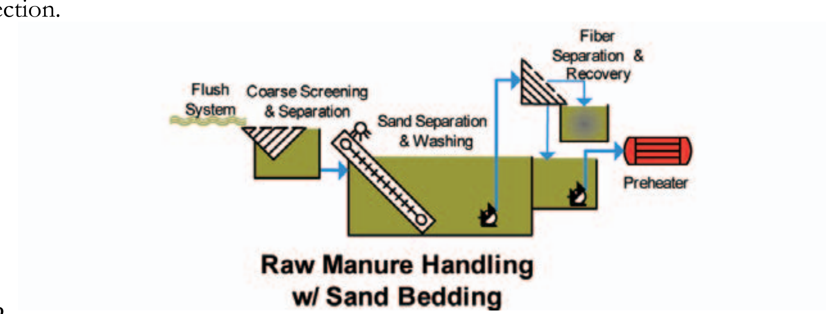
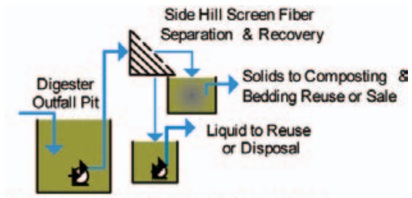


Sand bedding is generally considered the least compatible with agricultural anaerobic digestion due to the high level of dilution required to efficiently reclaim and reuse sand. Without sand reclamation, sand bedding is generally not economically viable. The high dilution factor has led to the development and selection of fixed film or hybrid digesters at some locations. Again, careful consideration of the overall economics is critical to financial success at most installations.



Post Digester Manure Handling w/ Fiber or Sand Bedding

Unless screened prior to digestion and regardless of the bedding type, a portion of the cellulosic fiber from forage crops will pass through a digestion process and be present for separation and reuse as bedding and/or compost. The above schematic illustrates a typical flow path for post digestion screening. As a rule, fiber separation after digestion is easier and more efficient due to the breakdown of nearly all viscous characteristic of raw manure. Depending on the process, there will be varying levels of fiber degradation during digestion.

Implementation Process

Overview – When considering the need for or value of an AD project, a systematic approach should be followed. The core steps and brief summary of each is provided herein for consideration.

Conceptual Review – This first step could also be termed the litmus test in that some very basic issues are tabulated and given a general analysis relative to need, cost and value. The basic questions that should be asked and answered are:

1. Is manure handling either an insect or an odor problem?
2. Are electrical costs either high or burdensome?
3. Is there a reasonable utility energy buy-back program?
4. Are there grants, rebates or low interest loans available?
5. Is there any pending or encroaching land zoning/use limitation?

Questions 1 & 2 are deal breakers in many cases in that a project to contain the manure may be required to remain operational at the current location. At this point, the incremental costs of capturing and utilizing the biogas are often very attractive.

Macro Economics – If a full scale energy project appears to have some financial feasibility after initial evaluation, a macro economic assessment should be completed. This should be accomplished with the guidance of an experienced company or individual. The evaluation should include an initial manure handling and digestion process assessment along with general capital, operations costs along with the value of potential rebates, energy savings and sales.

Detailed System Economics and Financing – If the macro economic assessment indicates an attractive return on investment, then a complete system analysis and selection process should be completed. This step is often referred to as a Design Memorandum where every process is sized, layouts proposed and all equipment is quantified. A detailed capital, operations and benefit analysis is completed at this point. Work through this step is generally required to receive funding commitments for either loans, grants or rebates. In general, successful and sustainable projects should be financially attractive with no grants or rebates and only enhanced by their availability.

Design – Using the design memorandum as the guiding document, the system will then proceed to formal design where professional engineers are retained to properly develop plans and specifications for construction. This process can be expected to take 4-6 months for most digesters and longer for large and/or more complicated systems.

Construction – This step may take several contract forms depending on the owner's level of sophistication and the system's size. The project can range from a turnkey design build to classic bidding and general contracting. Much will depend on the system selected and capability of the related vendors and/or contractors. Again, depending on the owner and the project size and complexity, 4-8 months may be required for construction.

Operations and Maintenance – Most successful systems have been so due to overall simplicity and relatively low operations and maintenance costs. This should be clear during the macro economic evaluation stage where complex systems can be ruled out if there are no net economical advantages. It should be considered critical for most operations that O&M be simple and reliable.

Sustainability – The sustainability of a project should be well determined prior to selection and design so that after startup, the system becomes the process and economic combination that was anticipated. The items that will affect sustainability are:

Sand bedding is generally considered the least compatible with agricultural anaerobic digestion due to the high level of dilution required to efficiently reclaim and reuse sand. Without sand reclamation, sand bedding is generally not economically viable. The high dilution factor has led to the development and selection of fixed film or hybrid digesters at some locations. Again, careful consideration of the overall economics is critical to financial success at most installations.

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1. Thorough and proper process selection
2. Process reliability
3. Quality of design and process equipment
4. Quality and commitment of owner and operations & maintenance staff
5. Attainment of economic objectives.

Summary

Overview – Determining the feasibility of using agricultural AD is fairly complex but attaining a reasonable level of success is achievable if systematically approached by knowledgeable owners and supporting professionals. It is critical that all facets of a system be understood prior to selection and proceeding with design and construction. Thorough appreciation, understanding and evaluation of all the interrelated factors are fundamental to a successful AD project.

Metabolism – Anaerobic metabolism within an anaerobic digester is a very robust process that when properly managed can yield many benefits to an agricultural operation. Methanogenic bacteria work in concert with several other types of bacteria to convert both complex and simple biodegradable organic compounds into CH_4, CO_2, H_2O, H_2S and biomass. The primary benefits are the production of methane gas which can be used for generating considerable energy in the form of heat and electricity and the co-combustion of H_2S to reduce odors. Animal manures are rich in anaerobic organisms and in particular, methanogenic bacteria. The bacteria can either continue the processes found in the animal gut to further breakdown raw manure or they can be leveraged through co-digestion of off-farm organics to produce much more energy than is available from just manure. An agricultural AD is very reliable and efficient when properly designed and operated.

Systems – A modern agricultural AD operation is comprised of several integral processes or systems. Each must be properly planned, designed, operated and maintained in order to maximize the overall operation's economic benefits. Failure of any one system can rapidly lead to overall system demise. It is critical that manure handling practices be matched to the digester in order that all systems function at their optimum level. Furthermore, the biogas/energy management system can vary from relatively simple to fairly complex. A complete evaluation of the site and utility integration factors must be accomplished in order to maximize the overall system's success and ultimate value.

Designs – Many AD designs have been developed. Each design has specific characteristics that when optimized will lead to a successful installation and operation. Careful consideration and analysis is required to assure that the best digester for the

operation is chosen. There is a very wide range in capital costs and ease of operation with the different designs. Most systems are designed with fairly long hydraulic detention times (20 days) but some have recently shown the ability to function at detention times less than 5 days. The biggest single factor that affects a digester is the type of bedding. In general, sand bedding is the least compatible with cost effective digesters and will rapidly plug most designs if it is not removed efficiently. On the other hand, fiber bedding can be accommodated in nearly all designs through the judicial use of appropriate screening devices.

Co-Digestion – The concept of co-digestion is a fairly recent development in agricultural AD systems. Historically, it had been thought that only long detention times at warm temperatures would lead to efficient manure breakdown. It turns out that the manure is actually a mass of under utilized bacteria that can process quite a large amount of outside organic material in addition to breaking down the contents of raw manure. Most evaluations have found that not only does the outside material breakdown quickly but there is typically a greater degree of volatile solids reduction of the original manure than would have occurred without the outside organics. This concept will continue to grow as more sites utilize the procedure and develop better understanding of the 'hidden' processing capacity of raw animal manure.

Energy & Economics – Interest in agricultural AD systems is usually initiated by the energy value realized when CH_4 is produced and utilized. In addition to energy however is the growing factor of odor control. In many locations animal operations can not continue without minimizing the normal odors associated with animal manure. An AD system effectively reduces the odor by converting sulfur from sulfates and proteins to H_2S which can be combusted in a flare, boiler, or engine and converted to odorless SO_2. The overall economic benefit of an AD is fairly complex and can vary widely between system designs. It is important that extensive review of the entire system be complete prior to design and implementation in order that economic risks are minimized. Often grants, rebates and low interest loans can be utilized to assist in AD projects. It is important to know the sources and understand the conditions for these economic incentives. In general, the economics should be attractive without financial assistance prior to proceeding as many systems have been abandoned due the overall poor economics of the system despite the assistance.

Implementation – A successful AD project demands that a systematic approach be followed. The steps include preliminary evaluations, macro economic analysis, micro economic analysis, financing plans and design memos, system design, construction, startup and sustainable operations plans. Failure to follow the systematic approach greatly increases the chance for financial disappointment or complete system failure. On the other hand, following a systematic approach generally leads to proper system selection and success.

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Estimating Energy Production Potential

The following example illustrates a simplified estimating approach for energy production potential per 1000 cows in each category. More refined estimates using site applicable data should be accomplished if the general energy production potential and regional considerations indicate a system investment deserves further consideration.

Daily Manure Production

Animal Type	Animal No.	% Collected	Cu.Ft./Animal	Cu.Ft./Day
Lactating	1000	100	1.8	1800
Dry/Heifer	1000	50	.9	450

Daily Gas Production

Animal Type	Cu.Ft. Manure	Cu.Ft. Gas/ Cu.Ft. Manure	Cu.Ft. Gas Production
Lactating	1800	37	66,600
Dry/Heifer	450	37	16,650
		Total	**83,250**

Estimated Generator Size

Cu.Ft./Day	Run Time	Cu.Ft./kWh	Generator kW
83,250	24	25	140

Energy Production from Cogeneration

Cu.Ft./Day	kWh/ Cu.Ft.	kWh/day
83,250	.033	2,747